Initial Thoughts on a Proposal for a Pbar Global Monitoring System

Current Monitoring of Pbar Source Operations

This document explores the possibility of implementing a Pbar Global Monitoring System. Pbar source operation is monitored and analyzed with a number of different tools including Acnet alarms, transient recorders, Lumberjacks, Acnet applications such as the Stack-o-meter and Life-o-meter, parameter pages, Acnet plotting packages such as fast time plots and snapshot plots, and diagnostic devices such as Network Analyzers, Spectrum Analyzers, and Vector Signal Analyzers. Each of these components has an important role in monitoring Pbar Source operations; however, there lacks a global system that ties all of these individual components together to provide a real-time analysis and baseline of the entire beam path and systems that compose the Pbar source.

The Acnet Alarm monitors individual control system parameters. Individual parameters are placed in alarm screen lists that are manipulated by individuals or Acnet sequencers to determine which devices are monitored. Both digital device status change and analog readings can be monitored. When a device goes into alarm, it posts a message on an Acnet console Alarm Screen as shown in Figure 1. The Acnet alarm screen is good for monitoring individual device failures, but is not designed to monitor more subtle trends in system behavior or beam efficiencies. A Pbar global monitoring system may be able to examine data from Pbar source beam and subsystems, perform calculations on the available data, and watch for trends that may not be detectible by the alarm screen. The global monitoring could then report it results to a user interface application or could report changing results in the form of non-beam inhibit or acknowledgeable alarms.

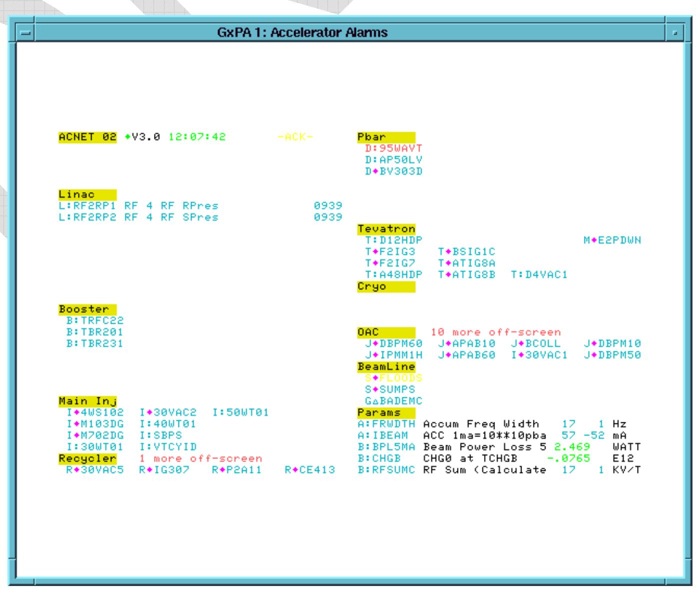

Figure 1: Typical Acnet alarm screen. Acnet console use the alarm screens to continuously monitor the accelerators. The Alarm screens are good for monitoring real

time problems with individual devices in the Pbar source, but is not designed to monitor subtle trends in system behavior or beam efficiency.

Long-term device trends and efficiencies are currently monitored using the Acnet Lumberjack. Individual parameter information is sampled and stored on Java control system computers. Users can user either the Acnet Lumberjack program D44 or its Java equivalent to access the data. Using Lumberjack, users can create simple plots of the data such as device over time, device1 verses device 1, or device1/device2 over time. More complex analysis can be completed by additional tools such as Java Analysis Studio (JAS). Detailed information on the capabilities of JAS can be found online at http://jas.freehep.org/. AD\Controls provides a JAS datalogger plug-in (http://www-bd.fnal.gov/SDAMisc/Jas3/index.html) that allows users to import the Acnet lumberjack data into JAS and perform analysis on the data. Such analysis allows users to make "cuts" on the data to discover more subtle information. For example, in Figure 2 we see two plots: one generated using D44 and the other using JAS. Both plots show the vertical emittance versus horizontal emittance in the Accumulator over the same time frame. However, the JAS plot as an additional cut on the data to show the emittance values only when a certain set of criteria are matched. In this plot the cut demands that we are in stacking mode, have a stack size between 60 and 70ma, and have a stack rate between 10 and 12 ma/hr. Close examination of data in this manner using different cuts could help determine a baseline set of values that we can define as expected values during good stacking. A global monitoring system could use the baseline values to compare current running conditions with expected running.

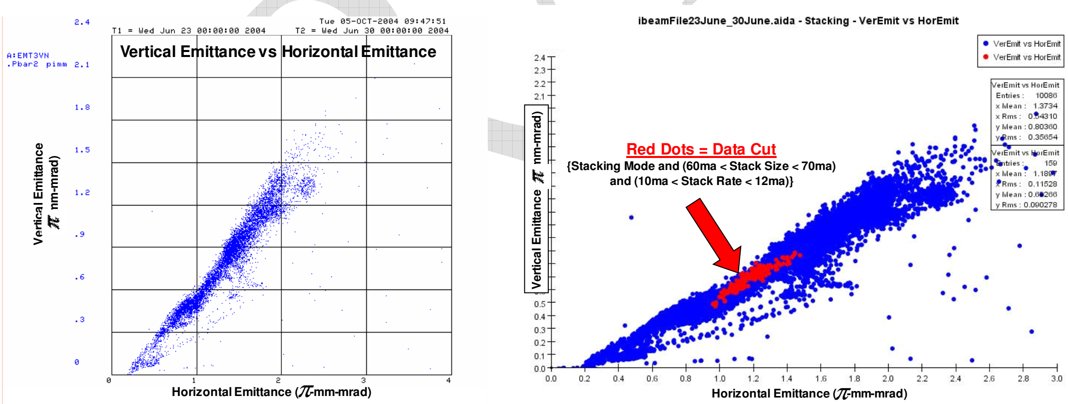

Figure 2: Comparison of common Acnet data analysis methods. The plot on the left is a Lumberjack plot of Accumulator vertical emittance versus the horizontal emittance from June 23 to June 30, 2004. The plot on the right is a JAS plot of the same devices over the same time frame. The blue dots represent the same data on both plots. The red dots on the JAS plot on the right show an additional cut on the data. The cut required that we be in stacking mode (APDMode = 7), stack size be between 60 and 70ma, and stack rate be between 10 and 12 ma/hr. Examining data in this manner can help us determine bench mark conditions for good stacking.

The Lumberjack also allows us to monitor accelerator trends that allow us to predict subtle failures not seen by the alarm screen, failures before they occur, or gradual changes in systems or beam performance. Figure 3 shows two examples of Lumberjack usage to find or predict problems. The left plot shows how the efficiency of beam collected off the target decreases when the target station target stops rotating. This type of failure is not posted on the alarm screen since the target's A/D value changes over time. The Lumberjack or a system that watches the slope of target rotation over time during stacking mode could catch this type of problem. The right-hand plot in Figure 3 shows the signature behavior of a device prior to failure. AP3 line shunts have a history of failure due to radiation damage. This problem was addressed by relocating the effected shunts during the fall 2004 shutdown, but this does not mean that we will never see this problem again. There is a signature behavior that the shunts exhibit days, weeks or even months before they fail. The operating current droops when in stacking mode. As the difference between the shunt current during stacking and shot modes increase, the shunt gets closer to failure. Eventually, the current differences are too great and the shunt cannot obtain operating current during a shot. Periodic inspection with the Datalogger can spot this type of problem before it occurs. It may also be desirable to watch for signatures of common failures like these in a global monitoring system. Datalogger analysis requires a user to manually acquire and analyze the data as the dataloggers do not provide real-time monitoring capabilities. A global monitoring system may be able to provide the benefits of the data analysis provided by the lumberjack, with near real-time reporting capabilities.

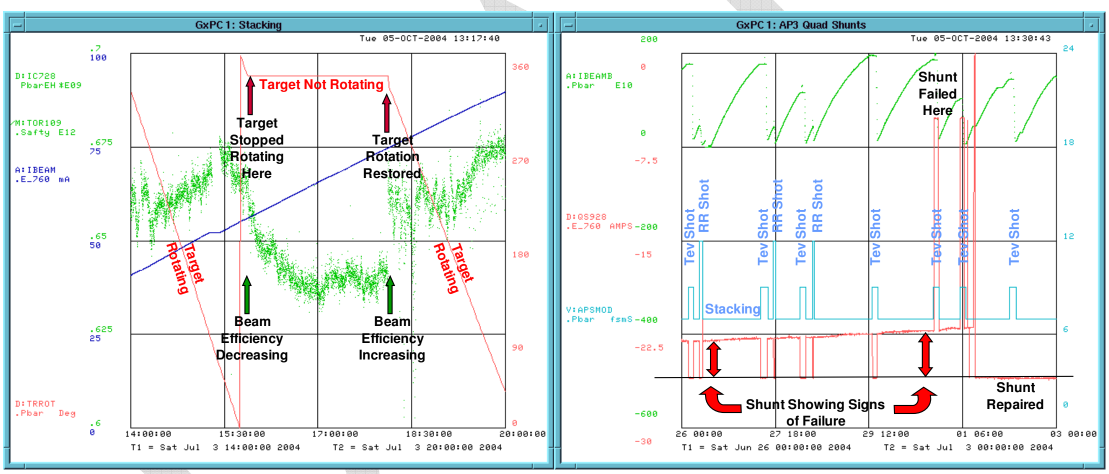

Figure 3: Two examples of datalogger plots being used to diagnose problems. On the left, the target stopped rotating (D:TRROT), which does not post an Acnet alarm. The green trace is beam at the end of the AP2 line normalized to beam on target. When the target stops rotating, the efficiency goes down. The plot on the right shows an AP3 line quad shunt's behavior prior to failure. The red trace is the quad shunt current, the blue trace is the Pbar operating state, and the green trace is beam in the Accumulator. We can see that there was a pattern to the shunt current behavior prior to failure of the shunt.

The Stack-o-meter and Life-o-meter are the primary operational tools for real-time monitoring of the Pbar source efficiency and stability in stacking and standby modes. Users can use either Acnet page P69 or the Java equivalent. The P69 version is normally run on the dedicated Console 101 comfort display in the Main Control Room, and can also be run on any Acnet console. The Stack-o-meter plots Accumulator beam intensity horizontal and vertical emittances, and beam delivered to the target all over an hour time frame. It also plots the calculated stack rate (Pbars accumulated in the core per hour) and. production efficiency (Pbars delivered to the core per 10^6 protons on target) and displays their values per cycle and their average over the last hour. The Stack-o-meter is an important tool used to monitor the Pbar source beam. Close examination of the parameters on this plot for various stack sizes, cycle times, and system configurations can lead to a set of baseline numbers for normal stacking. A Pbar global monitoring system could watch those numbers for changes when stacking becomes less efficient, and could be expanded to cover a more broad range of beam diagnostic devices and/or a global set of Pbar systems.

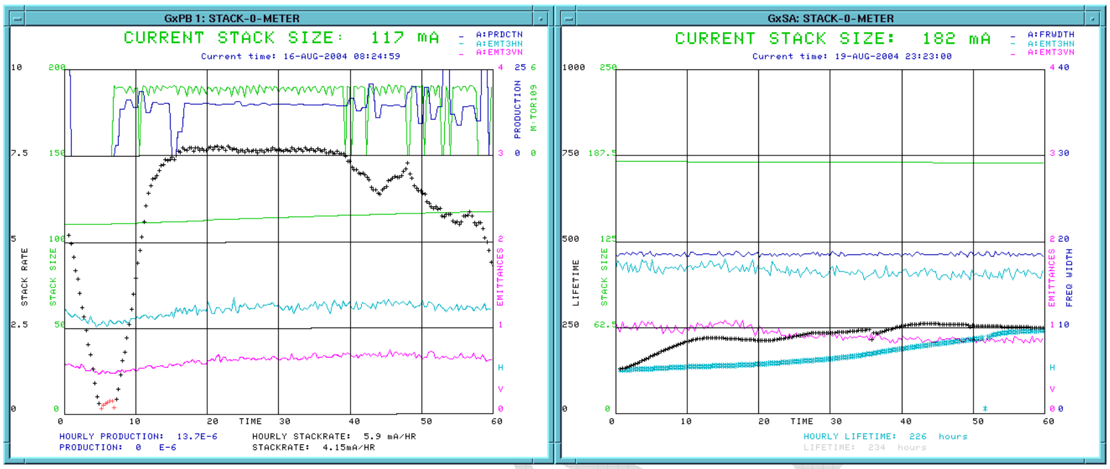

Figure 4: The left plot is the Stack-o-meter is used to monitor stacking conditions. The time-scale is over an hour. The green and blue traces in the top box are beam on target (M:TOR109) and production efficiency. The green trace with an upward slop in the center is the beam in the Accumulator. The cyan and magenta traces are Accumulator horizontal and vertical emittances. The black crosses are the stack rate (notice that they turn red when the stack rate is negative). The plot on the right is Life-o-meter, which is used in place of the Stack-o-meter when we are not stacking. The traces are similar, except there is no beam on target nor production efficiency, and there is an additional cyan trace that calculates the beam lifetime.

The Java equivalent of the Stack-o-meter is the Pbar Performance Plots. In addition to cloning the Stack-o-meter's real-time monitoring capabilities, the Java Pbar Performance Plots package has datalogging and plotting features. Figure 5 below shows two plots generated by the Pbar performance plots. The left plot shows the Pbar beam performance over a one week time frame. The right plot shows the normalized stack rate verses stack size taken over two different periods of time. Plots like these can provide a baseline for good stacking. The Pbar performance plots are normally run by mobile users and Pbar experts at their desktop or at home through the Fermilab VPN to monitor Pbar source operation. The lumberjack capabilities allow this program to analyze running conditions from any time. Close analysis of this data during good stacking conditions could allow this tool to help develop baselines for normal operation. Once the baselines have been established, a global monitoring system may be able to watch Pbar source trends based on the baselines.

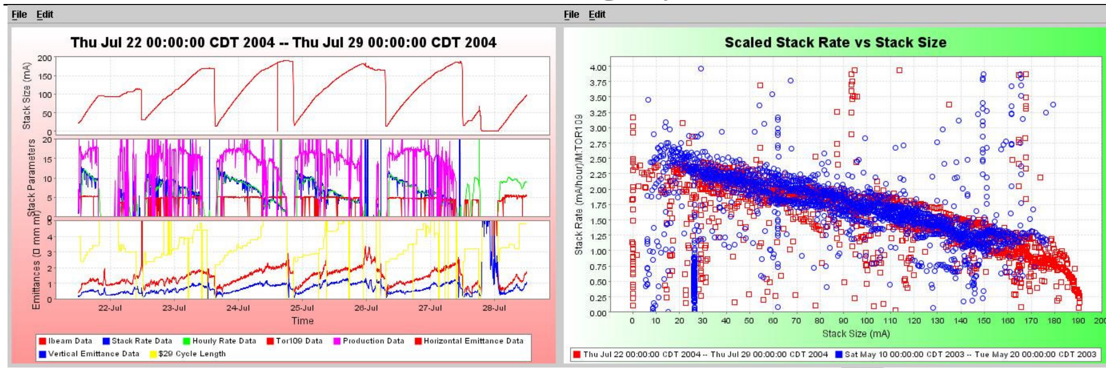

Figure 5: Java Pbar Performance Plots. The left plot is a weekly summary of Pbar operations, which provides the same data as stack-o-meter, except over a much larger time frame. The plot on the right is a stack rate (normalized to beam on target) versus stack size. The red circles show data taken over one week in June

Acnet Fast Time Plots or Snapshot plots can determine baseline behaviors for systems or beam signals at a sample rate higher than is available through the dataloggers. The plot on the left in Figure 6 shows Debuncher Horizontal TWT power levels with gain ramping enabled during a typical stacking cycle. Plotting normal behavior for these signals and noting beam conditions could determine a baseline for normal operation. The plot on the right of Figure 6 shows how baseline operating conditions may depend on the state of other systems or accelerators. The plot shows AP1 loss monitors during a time when there were alternating mixed mode $21 cycles (both Pbar stacking and SY120 slow spill) and stacking $29 cycles. Theses loss monitor plot was started just after the $21 mixed mode event and just prior to the normal $29 stacking cycle. Note that the loss values from the previous $21 cycle (left portion of the plot up to 0.8 seconds) are different than the loss values from the $29 cycle (after 0.84 seconds). This is due to the fact that some of the loss monitors are located in the Tevatron enclosure and integrate losses from the SY120 slow spill. Developing a baseline for these loss monitors would require knowledge of both beam conditions as well as the Accelerator operating state (stacking only versus mixed mode). If an operating baseline for the AP1 loss monitors was constructed for a global monitoring system, then the system would have to contain the logic to determine this information. Many other system and beam conditions rely on other systems or the current accelerator state. It would be a challenge to design a global monitoring system that has logic built in to adjust to the changing conditions. In addition, it may be too resource intensive to monitor devices at typical FTP or SNP sample rates, crunch the data and provide useful results.

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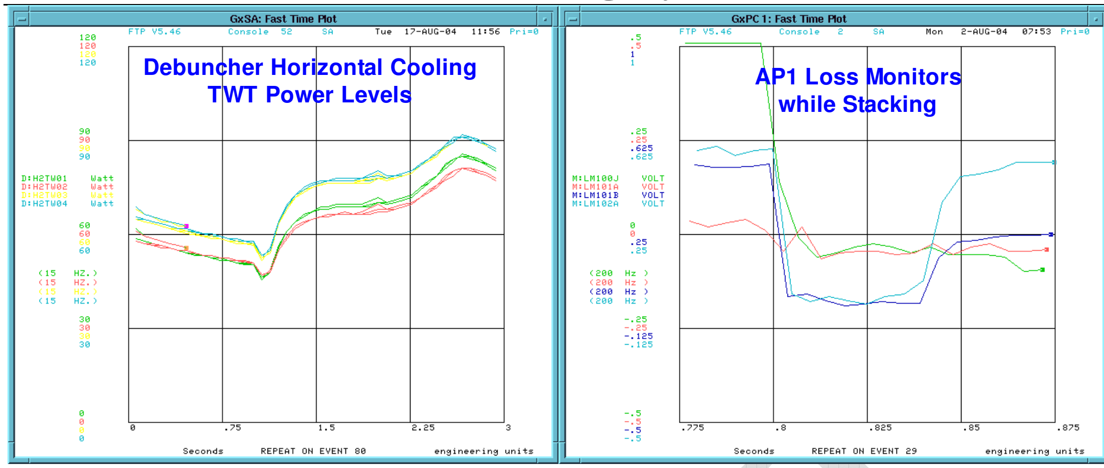

Figure 6: The plot on the left shows some of the Debuncher horizontal TWT signals. The plot on the right shows AP1 line losses. Plots like these could be used to determine baselines for normal operation.

There are numerous Acnet applications that examine Pbar data that could be used to help determine normal baseline behavior for both system and beam signals. The screen on the left of Figure 8 shows one of many pages of vacuum readbacks in the Pbar source. Information from pages like these could help us form a baseline for normal operation for all the vacuum systems. A global monitoring system could then watch for subtle changes in components or groups of components in that vacuum system. The plot on the right in Figure 8 is the BPM oribit in the P1, P2 and AP1 line during a typical stacking cycle. A drifting orbit could result in higher losses and decreased beam intensity. A global monitoring system may be able to periodically sample data such as the BPM positions to watch for subtle changes in the orbit over time.

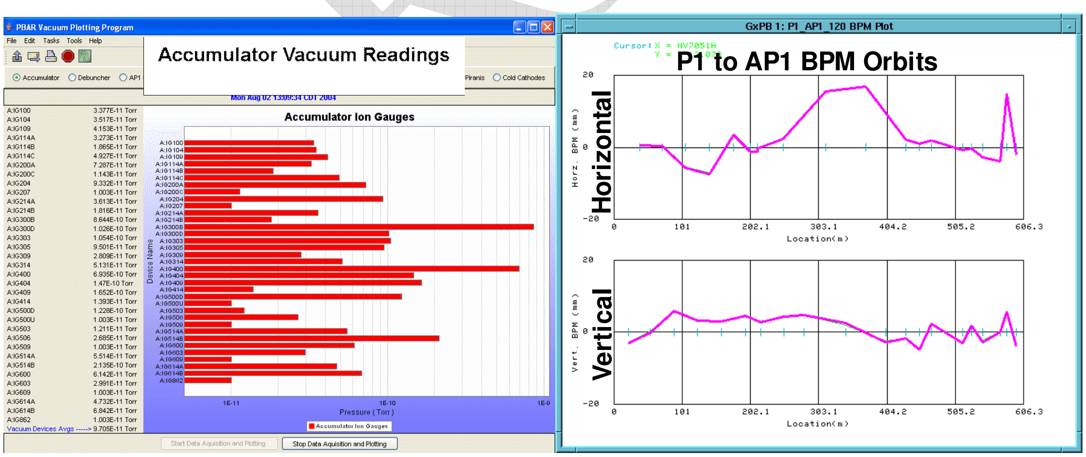

Figure 8: The plot on the left is an Accumulator Vacuum display. The plot on the right is the BPM orbit from P1 to AP1. Examination of application data like this could allow a baseline for normal operation to be developed.

Some useful ACNET parameters are only populated when their associated application is being run. Figure 9 shows two examples of this. The first plot shows Acnet program P101. When running, this program calculates the Debuncher injection flux and phase.

The plot on the right in Figure 9 is the SA launched from P142. This SA is using the VSA to look at the longitudinal profile in the Accumulator. This data is used to calculate the Accumulator center frequency A:CENFRQ. Collecting data similar to that seen in Figure 9 could be used by a Pbar global monitoring system to establish an operating baseline of operation. The problem is the parameters populated by these applications require the applications to be running. So a global monitoring system would need to have means of automatically calculating these values in the background.

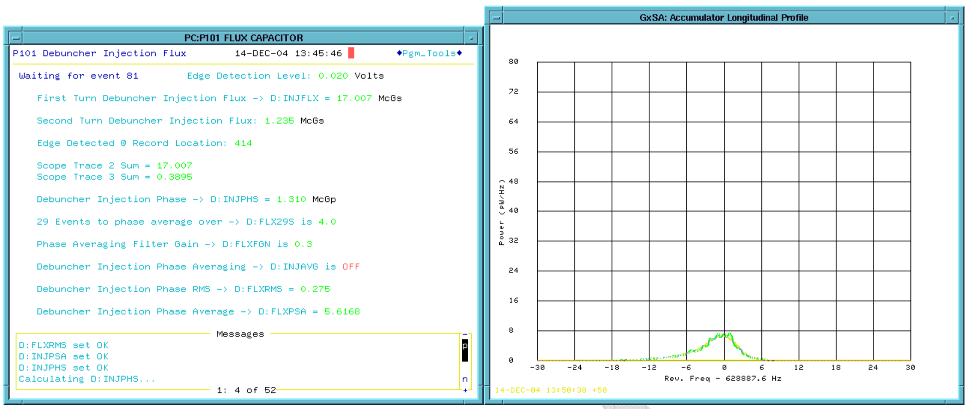

Figure 9: The plot on the left Acnet application P101. When running, this program connects to the flux capacitor scope and generates Debuncher injection intensity and phase information. The plot on the right is the SA launched from P142. When running this SA calculates A:CENFRQ.

Some scope traces provide read-back capabilities through Ethernet connections. It may be possible to periodically sample these scope traces and analyze them for differences between updates and post a warning if any of the traces change. All of the kickers have scopes attached with web interfaces. The plot on the left of Figure 10hows the three Debuncher extraction kicker tubes. Examining these traces over time could give us a baseline for normal operation. If a global monitoring system could periodically examine the data on the scope trace, it may be able to determine when a tube fails or gets severely mistimed. Such a diagnostic could save valuable troubleshooting time in the event of kicker problems. The plot on the right of Figure 10s the AP10 flux scope. The cyan trace is the injected Debuncher beam. Beam structure collected off the target is a reflection of beam input on the target. So, if Main Injector provides beam with missing or inconsistent bunches, you will likely be able to see it on the scope. A periodic examination of the traces along with beam conditions could allow a baseline to be constructed. A Pbar global monitoring system could periodically monitor traces like these for problems. There are a number of other web accessible scopes used in Pbar. It may be possible that a Pbar global monitoring system could periodically sample data from a number of them to watch the health of the Pbar source.

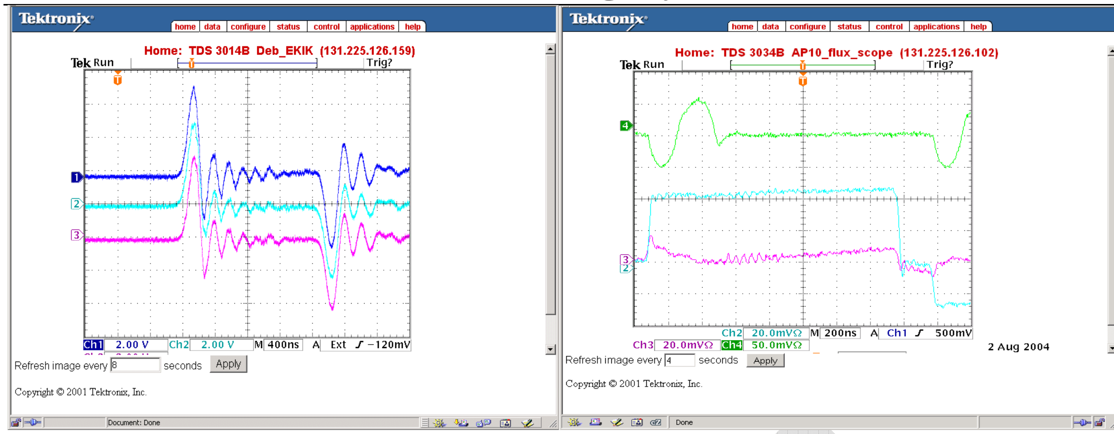

Figure 10: Network Scope Traces. The picture on the left is the Debuncher Injection Kicker Thyrotons firing. The picture on the right is the AP10 flux scope.

Important beam and system analysis is obtained by connecting Schottky detectors and other system signals to Spectrum Analyzers, Network Analyzers and Vector Signal Analyzers. The plot on the left of figure 11 is the Debuncher Momentum band 2 cooling signal DP2-SCH sampled at h=8813 of the revolution frequency by a spectrum analyzer. The green trace is sampled at injection, which is the normal bunch rotation display. The other traces are taken by triggering the same spectrum analyzer signal at successively later times, with the dark blue trace taken at the end of a stacking cycle. Close examination of these traces could help determine a baseline for bunch rotation and Debuncher momentum cooling. The plot on the right of Figure 11 is the same signal, sampled at the end of the Debuncher cycle with the span zoomed in. Examination of this spectrum analyzer trace can show the revolution frequency of the beam as well as the momentum width. Cycling DRF2 can also show the effective alignment between the DRF and Debuncher cooling. If a global monitoring system had at least one dedicated spectrum analyzer channel, it could periodically examine spectrum analyzer signals like these to determine a normal baseline for Debuncher beam behavior. Connecting to, configuring and collecting data from each spectrum analyzer would take a finite amount of time, limiting how frequently information could be sampled. Multiple dedicated spectrum analyzer channels could increase the amount of data that could be collected and examined.

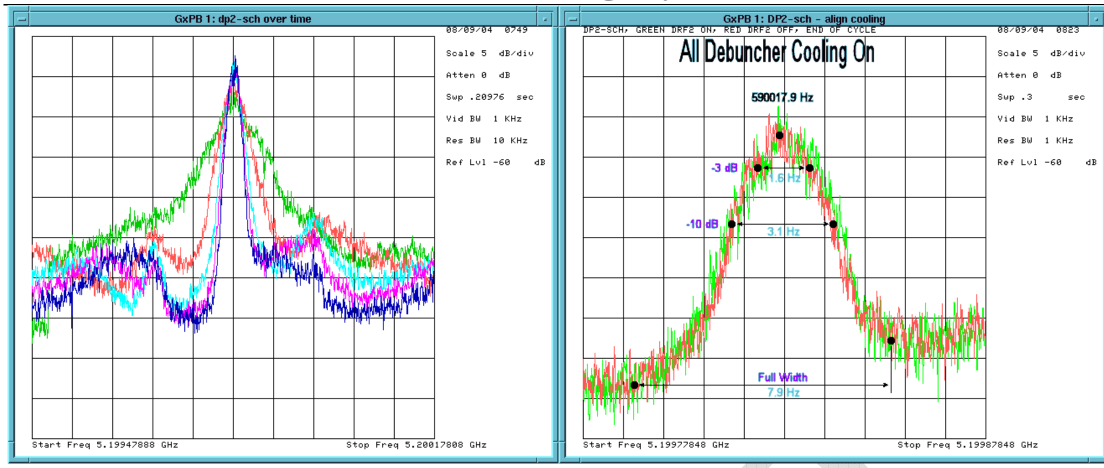

Figure 11: Debuncher Momentum band 2 cooling signal DP2-SCH over time. The green trace is taken at bunch rotation time. The other traces are taken at successively later times. The dark blue trace is taken at the end of the cycle. The plot on the right is the same signal, sampled at the end of the Debuncher cycle with the span zoomed in. Examination of traces like these could allow us to establish baselines for Debuncher beam operation.

Figure 12 shows spectrum analyzer data from the Accumulator Longitudinal Schottky signal. The plot on the left is the normal Accumulator profile display. A baseline of normal Accumulator operation could be determined by close examination of this trace. The height of the bump on the injection orbit is the amount of beam left after ARF1 has moved the beam to the deposition orbit. If the Debuncher extracted energy changes or if ARF1 drifts out of tune, the height and location of the bump may change. The shape of the stacktail could also be examined noting conditions such as $81 cycle time and beam intensity to determine when excessive backstreaming or other stacktail problems occur. Examining the core could give you values for the revolution frequency and frequency width, which is currently being implemented by OACs written by Paul Derwent. Additional information can be determined from the same Schottky detector by changing the trigger time of the spectrum analyzer. The right plot in Figure 12 shows the Accumulator Longitudinal Schottky signal sampled on two spectrum analyzers sampled during the same stacking pulse, but at two different trigger times with a Java program written by Paul Derwent. The red trace shows when beam is injected and the blue trace shows with ARF1 has moved injected beam to the deposition orbit. The two plots can be compared to determine the efficiency from injection to deposition orbit. If this comparison was made periodically, a baseline for normal injection to deposition orbit efficiency could be developed. If a Pbar global monitoring system could have one or two dedicated spectrum analyzer signals, it could periodically analyze the Accumulator Longitudinal Schottky to develop baselines for normal operation.

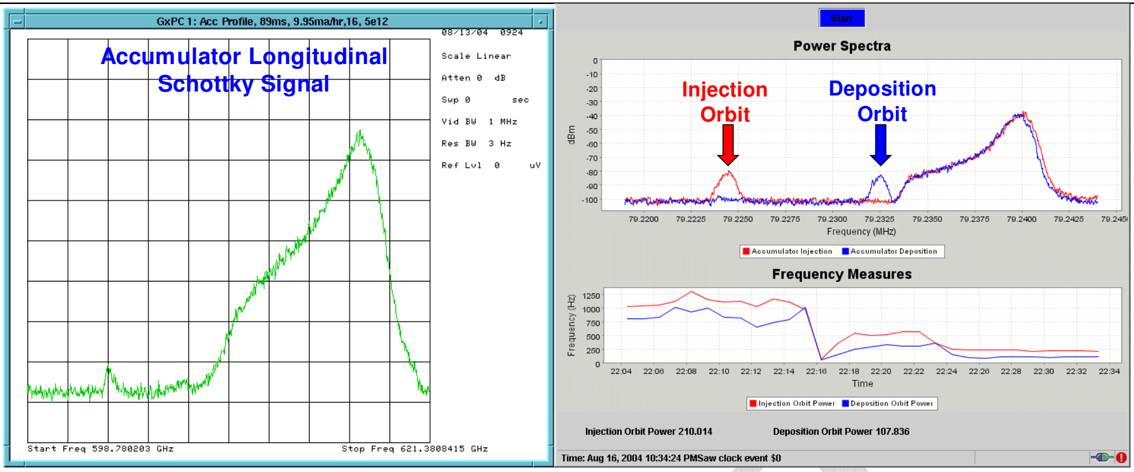

Figure 12: Accumulator profiles. The left plot is the normal Accumulator profile display looking at the Accumulator Longitudinal Schottky after beam has been moved from the injection orbit to the stack tail. The plot on the left has two spectrum analyzers both looking at the Accumulator Longitudinal Schottky signal during the same pulse. The red trace is sampled at beam injection time and the blue trace is sampled when ARF1 has moved beam from the injection orbit to the deposition orbit.

So far, we have discussed a number of different mechanisms that are currently used to monitor the Pbar source and briefly touched upon how these systems could be enhanced by the addition of a global monitoring system. Clearly a global monitoring system that would incorporate all of the above systems in every way mentioned above would be an incredibly aggressive, challenging and resource intensive process. The challenge is to find a subset of systems to incorporate into a global monitoring system that won't take an overwhelming amount of resources to complete, but still provide us with a useful system.

Desired Features for a Pbar Global Monitoring System

Would it be possible to construct a global system that ties many of the above mentioned individual components together to provide a real-time analysis and baseline of the entire beam path and systems that compose the Pbar source? Implementing such a system would be a significant challenge as it would require significant manpower and resources to both develop and run. Which systems would we chose to incorporate into our new monitoring system? Also, is there monitoring functionality that can not be achieved by using other systems? If so, do we need to develop new systems to meet that functionality. Where can we start to outline what systems we want to incorporate? Let's develop a wish-list of desirable features and use that list to narrow our possibilities.

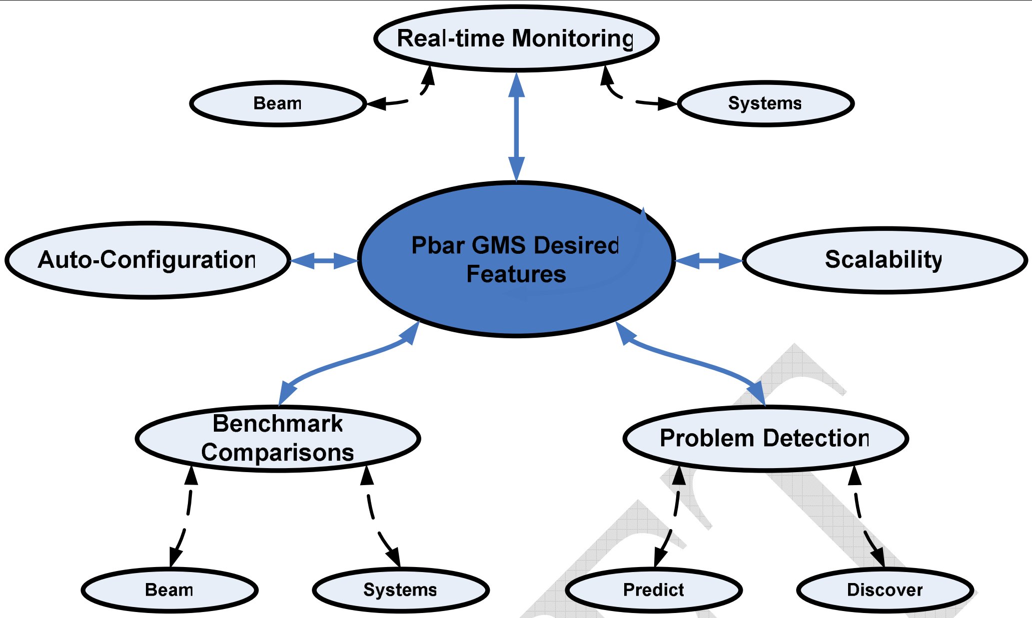

Figure 13: Pbar GMS desired features. A Pbar Global Monitoring system would need to perform real-time monitoring of both beam and systems, auto configuration, scalability, benchmarking of both beam and system, and problem prediction and discovery.

Figure 13 is a flow chart that displays the desired features of our new monitoring system. The medium blue oval in the center represents our new monitoring system. The light-blue ovals with connecting lines to the center oval represent the desired features. A description of each desired feature is given below.

1. **Automatic Configuration**: The new monitoring system must adjust automatically to changing operating conditions by keeping track of the Pbar operating state and beam conditions. If our global monitoring system is reporting on stacking efficiencies, we must be in stacking mode and the upstream accelerators must be providing beam. If we are in shot setup, we may not want to be reporting on stacking efficiencies.
2. **Continuous near-read-time monitoring**: The global monitoring system must continuously monitor the Accelerator and report back information in near real-time through a user application interface and/or Acnet alarms. One possibility is to have OACs running in the control system that continually monitor various diagnostics in the Pbar source. These OACs could then output their data to Acnet parameters. Two sub-categories of real-time monitoring are:
    a. **Beam signals**: Monitoring beam intensities, efficiencies and quality throughout the Pbar source could give an indication of the overall condition of the beam. Monitoring core stability during stacking and standby modes could be useful. Our global monitoring system could also give us an early warning indication of trends or subtle changing beam conditions.

   b. **System status**: Systems such as Stochastic Cooling, LCW, and Vacuum could be also monitored to give an indication of the overall heath of these systems.
3. **Benchmark Comparisons**: One of the most important features of the global monitoring system is the ability to benchmark ideal conditions. As examined in the previous section we can obtain benchmark information from a number of different sources that would allow us to analyze machine conditions to see trends and establish performance benchmarks for both beam efficiency and individual Pbar subsystems. The global monitoring system would collect data from various systems, perform useful calculations on the data if necessary, and compare the results to standard baseline values.
   a. **Beam**: We want to be able to monitor Pbar source beam efficiencies much like the stack-o-meter/life-o-meter, but over a much broader scope of devices. If stacking efficiencies decrease, we want a more granular view of beam intensities and qualities that allow us to quickly pin point the source.
   b. **Systems:** Detecting subtle trends and changing conditions in these systems may allow the detection of problems before they are severe enough to affect beam.
4. **Problems Detection**: A global monitoring system could help detect problems when they occur. It could leverage the Acnet alarm capabilities to post non-beam inhibit or acknowledgeable alarms when subtle problems are detected.
   a. **Detection**: Datalogger plots allow us to examine trends in systems to pin point the source of problems as they occur as was shown in the target rotation example in Figure 6. Ideally, a global monitoring system should be able to watch for common failure signatures and report any discoveries in near real-time.
   b. **Prediction:** Certain systems exhibit signature behavior before they experience failure as was discussed in shunt example in Figure 6. Our system must be able to spot common problems and failure signatures.
5. **Scalability**: The new system must be able to easily be changed to allow for:
   a. New and/or changing instrumentation and diagnostics.
   b. New failure signatures as new problems arise.
   c. Changing system characteristics as systems are updated.
   d. Changing beam efficiencies as we make improvements.
   e. Component failure.

Time and resources may not allow us to implement all of the desired features in our Pbar global monitoring system. We will next look at how we could logically divide our new system into functions. We will call our new system the Pbar Global Monitoring System (Pbar GMS for short).

Pbar GMS Primary Functions

A Pbar Global Monitoring System (Pbar GMS) will provide a continuous global view of Pbar source operation. It will watch for trends in operation and provide an advance warning of global problems. It will have logic built in to self-determine the operating state of the Pbar Source, so that it can change how devices and systems are monitored based on that operational state. It will also modify its monitoring thresholds based on the current beam conditions. This will allow the Pbar GMS to provide a bench mark of expected performance based on the machine conditions.

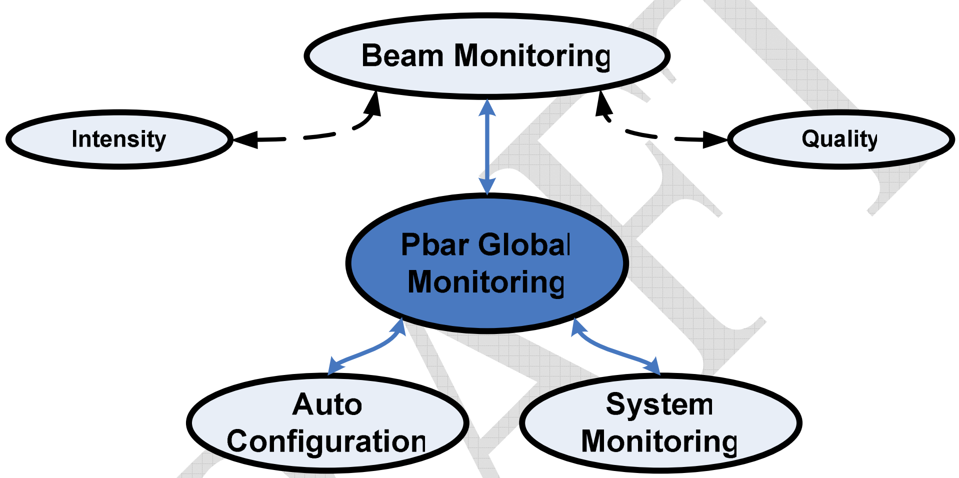

Figure 14: The three functional categories of the Pbar GMS are auto configuration, beam monitoring and system monitoring.

If we examine Figure 13 from the last section and the accompanying text, we can see that our feature sets could be reorganized into three categories: auto configuration, beam monitoring and system monitoring. Figure 14, shows these three categories. Auto configuration is brains of the Pbar GMS. It would allow the Pbar GMS to change monitoring states that reflect the accelerator and beam conditions. Beam Monitoring, which can be broken down into intensity and quality subcategories, includes all of the real-time monitoring, benchmarking and problem detection gathered from beam diagnostics. The System Monitoring includes all of the real-time monitoring, benchmarking and problem detection for Pbar sub-systems. All three categories are independent of each other and could be implemented separately.

Auto-Configuration

The Pbar GMS would need to determine the Pbar operation state so that it can monitor the accelerator properly. Three common states in the order that they would likely be implemented into the Pbar GMS are stacking, standby and unstacking modes. During stacking we would want to examine the entire beam chain from extraction from Main Injector all the way to the Accumulator core. During standby time, we would want to monitor the stability of the Accumulator core. During unstacking we would want to monitor the efficiency of the transfers. This section will cover what devices and systems the Pbar GMS could use to properly determine the operational state of the Pbar Source.

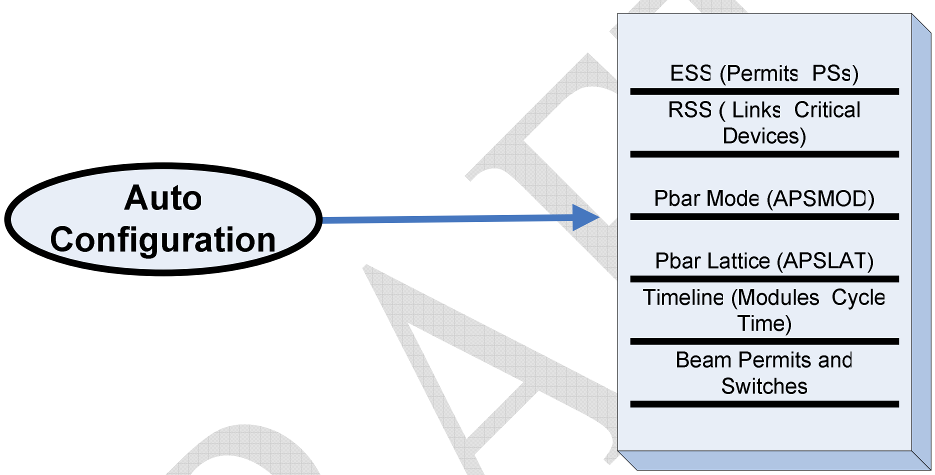

Figure 15: Implementing an auto configuration feature to the Pbar GMS would require knowledge of the safety system permits, Pbar mode, Pbar lattice, timeline, beam permits and beam switches.

1. **Safety System Status**: The first step is to determine the Safety System status for each interlocked enclosure in Pbar. We can break the Safety System status down into two categories: Electrical Safety System and Radiation Safety System.
    a. Electrical Safety Systems (ESS): If ESS permits are not made up, then there is no use having a Pbar GMS try to collect data for beam in those enclosures.
        i. Permits:
            1. Tev F-Sector
            2. Pre-Target
            3. Pre-Vault
            4. Vault
            5. Transport
            6. Rings
        ii. Power Supplies: If permits exist, are all the power supplies for each turned on?

   b. Radiation Safety Systems (RSS): The RSS status could help the Pbar GMS determine which enclosures are ready to accept beam. This still does not tell us if there is beam in those enclosures.
      i. Critical Devices Controllers
         1. D:AP0CD0 (Pre-Vlt/Vlt/Xprt)
         2. D:AP0CD1 (PTgt/PVlt/Vlt/Xprt)
         3. D:AP0CD2 (Rings/Xprt)
      ii. Critical Devices: If permits exist, are the critical devices powered?
         1. Rings/Transport
            a. D:H704 and D:BSC700 (AP2 line injection)
            b. D:H926 and D:BSC925 (AP3 line extraction)
         2. Pre-Vault/Vault/Transport
            a. M:HV100 and I:F17B3 (stacking)
            b. M:HV200 and I:F17B3 (8 Gev)
         3. Pre-Target/Pre-Vault/Vault/Transport
            a. D:V730 and D:H717
            b. D:V901 and D:H914
         4. Rings Coasting Beam
            a. A:BV607
            b. D:BV610

2. **PBar Mode**: Once we have ESS and RSS permits we are capable of running beam. Next we need to determine the operating state of the Pbar source to see which of the enclosures is likely to have beam. We may be able to use the state parameter V:APSMOD to determine the operational state of the Pbar source. V:APSMOD is changed through the Sequencers when operational aggregates are run. It has the following states:
   a. 1 = shutdown
   b. 2 = Access
   c. 3 = Diagnosing Failure
   d. 4 = Repairing Failure
   e. 5 = Recovery/ Turn-on
   f. 6 = Standby
   g. 7 = Stacking
   h. 8 = Reverse Protons
   i. 9 = Pbar Shots to Tevatron
   j. 10 = Deceleration
   k. 11 = Store
   l. 12 = Pbar shots to Recycler
3. **Pbar Lattice**: We may also want to know which lattice the Accumulator is running. We may be able to use the state parameter V:APSLAT, which shows the lattice state of the Accumulator. is changed through the Sequencers when operational aggregates are run. It has the following states:
   a. 1 = Stacking Lattice
   b. 2 = Unstacking Lattice

4. **Timeline (TLG)**: Once the operational state of the Pbar source has been determined, we will need to examine which Timeline modules have Pbar beam events.
    a. Beam Events: What Pbar events occur
    b. Cycle Time: What is the spacing between the Pbar events.
5. **Beam Permits and switches**: To know if we are asking for Beam, the Pbar GMS must know the status of the Beam Permits and beam switches.

All in all, the Pbar GMS could use the ESS, RSS, V:APSMOD, V:APSLAT, TLG, Beam Permits and Beam switches to determine what Pbar source enclosures have or are receiving beam. The Pbar GMS may be able use this information to automatically adjust its monitoring to match the operational state of Pbar.

Beam Intensity Monitoring

Monitoring beam in the Pbar source could be broken down into two broad categories: intensity monitoring and quality monitoring. This section will cover beam intensity monitoring. Beam intensity monitoring involves collecting the beam intensity at various spots in the Pbar Source using many of the existing diagnostics already available. The data may be analyzed, compared to baselines of expected operation, and output to a user interface, acnet parameters or the alarm screen. The intensity monitoring would watch efficiencies and the expected baseline efficiencies would have to adjust based on the accelerator operational state and beam conditions. Figure 17 and the following text outline systems that could be incorporated into a beam intensity monitoring system.

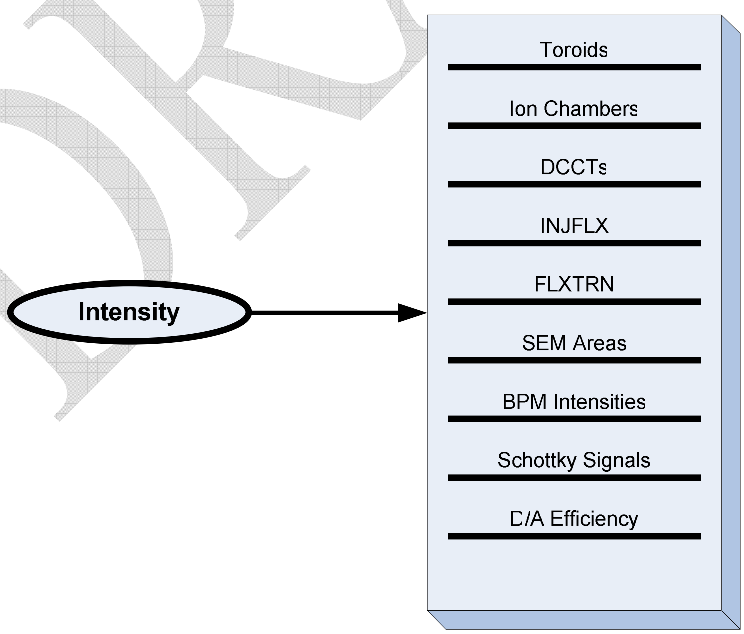

Figure 17: Beam Intensity Monitoring could be broken down into the following types of devices.

Initial Thoughts on a Proposal for a Pbar Global Monitoring System

The beam intensity would be monitored throughout the entire Pbar source. The beam intensity efficiency could be calculated from some or all of the below devices.

1. MI
    a. Toroid (I:TOR521)
2. A1 Line (unstacking)
    a. 914 Toroid (I:TOR914, I:AT914, I:TR914D, I:914DAV)
    b. 902 Toroid (I:TOR902, I:AT902, I:TR902D, I:902DAV)
3. P1 Line (Stacking)
    a. Toroids
        i. I:TOR702
        ii. I:TOR714
    b. SEMs: Not likely to be used due to their destructive effects on beam.
4. P2 Line (Stacking or Unstacking)
    a. F16 Toroid (I:TORF16, I:TRF16S, I:TRF16D, I:ATF16S, I:F16DAV)
    b. SEMs: Not likely to be used due to their destructive effects on beam.
5. AP1 Line
    a. Toroids
        i. TOR105 (M:TOR105, M:TR105B)
        ii. TOR109 (M:TOR109, M:TR109L, M:FFT109)
    b. SEMs: Not likely to be used due to their destructive effects on beam.
6. AP3 Line (Unstacking)
    a. Toroid (D:TOR910)
    b. SEMs: Not likely to be used due to their destructive effects on beam.
7. AP2 Line
    a. New large aperture Toroids (I:TOR704?, I:TOR724?)
    b. SEMs: Not likely to be used due to their destructive effects on beam.
    c. Ion Chamber (D:IC728) – Output is believed to not be linear, so care needs to be taken when using this diagnostic.
8. Debuncher
    a. D:INJFLX – requires VSA program to be running
    b. D:FLXTRN to D:FLXTRN[10] – requires VSA program to be running.
    c. Bunch Rotation Efficiency
        i. Calculate area under bunch rotation display off of the SA during bunch rotation and late in the cycle to make some determination on amount of beam surviving the Debuncher.
    d. DCCT: D:IBEAM
    e. FFT Currents (D:DBPWR1 and D:DBPWR2) – needs VSA program to run

9. Accumulator
    a. FFT Currents (A:ACPWR1 and A:ACPWR2) – needs VSA program to run.
    b. Accumulator from Accumulator profile?
    c. ARF1 Efficiency
        i. From SAs, calculate “Area of deposition orbit beam“ / “Area of injection orbit beam” by changing the timer and comparing two SAs?
    d. DCCT (A:IBEAM)
10. Stack Rate
11. Production Efficiency

Monitoring beam intensity from Main Injector extraction all the way to the Accumulator core could give us important data; however, the far more information can be learned by looking at beam structure and quality.   That is the topic of the next section.

Beam Quality Monitoring

Beam intensity monitoring involves watching the beam intensity at various spots in the Pbar Source. Beam quality monitoring is a little more involved. It involves examining various diagnostics, possibly performing analysis on the collected data, and outputting some indication as to the changing quality of the beam. Beam quality can included such things as beam profiles, orbits, bunch structures, frequencies, frequency widths, etc… Beam quality during stacking could include both the incoming stacking pulses as well as the circulating Accumulator beam. Beam quality monitoring during standby mode would focus on Accumulator stability. Figure 18 and the accompanying text describe possible systems that could be used to monitor beam quality.

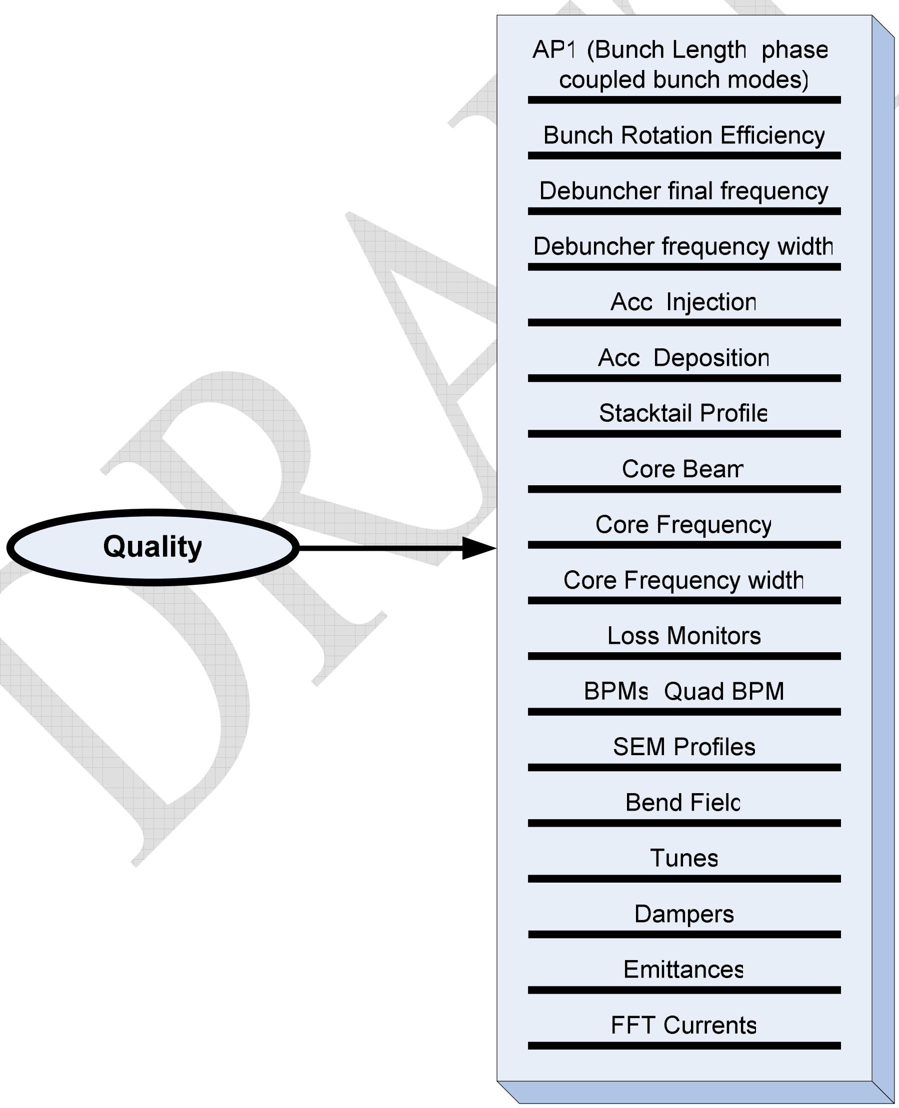

Figure 18: Devices that could be used in a beam quality measurement.

1. P1-P2 Lines
    a. BLMs
    b. BPM orbits
    c. SEM profiles: Not likely to be used due to their destructive effects on beam.
2. AP1 Line
    a. Proton Torpedo – requires scope setup and application to be running.
        1. Bunch Length
        2. Bunch Phase
        3. Coupled Bunch Modes
    b. BLMs
    c. BPM orbit
    d. SEM Profiles: Not likely to be used due to their destructive effects on beam.
3. AP3 Line
    a. BLMs
    b. BPM orbit
    c. SEM Profiles: Not likely to be used due to their destructive effects on beam.
4. Debuncher
    a. Bend Field
    b. Tunes
    c. Loss Monitors
    d. Orbit
    e. Bunch Rotation (calculate from Bunch Rotation SA)
    f. Frequency and momentum width (examine from SA set late in cycle?)
5. Accumulator
    a. Bend Field
    b. Tunes/Chromaticity
    c. Loss Monitors
    d. BPM Orbits
    e. Quad BPM
    f. Flying Wire -
    g. Examine Accumulator Longitudinal Schottky signal
        1. Area of injection orbit
        2. Area of deposition orbit
        3. Area and shape of Stacktail
        4. Core center Frequency (Z:CENTFR)
        5. Core frequency width (Z:FRWRMS, Z:FRWD95)
    h. VSA – requires VSA application to be running.
        1. A:VSARST
        2. A:VSAFWD
        3. CENFRQ,
        4. A:FRDWTH

i. Dampers
j. Clearing Electrodes
k. ARF?
l. Beam feedback on cooling systems
m. Signal Suppression

Monitoring Beam Quality could potentially give us an incredible amount of information. However, there are some significant challenges of monitoring beam quality. Some Diagnostics are destructive to beam (i.e. SEMs, Flying Wires) and cannot be continuously used. If the data collected from these devices becomes a high priority, then it may be possible to design the Pbar GMS to occasionally collect data from these devices, so as not to be too destructive to the beam. Another challenge is that some of our diagnostics currently require certain scopes to be setup (which occasionally may be used for other things). A Pbar GMS system would have to have either dedicated hardware or the ability to periodically take over scopes and certain spectrum analyzer channels. Also, some diagnostics require an Acnet application to be actively running in order to generate Acnet parameters. A Pbar GMS may be able to be designed to automatically generate these parameters without having to manually start their associated applications.

Systems Monitoring

Carefully monitoring Beam intensities and quality with the Pbar GMS would give us a good indication as to the overall beam performance; however, this does not give us the entire picture of the overall heath of the entire Pbar source. The Pbar source can be broken down into a number of individual sub-systems that are needed for efficient operation. This includes systems such as the LCW systems, Stochastic Cooling systems, and vacuum systems. The Pbar GMS could be designed to carefully monitor the health of these sub-systems and possibly report problems before their effects can be seen in the beam. Data from each system would need to be periodically collected, analyzed, compared to baselines of expected operation, and output to a user interface, Acnet parameters or the alarm screen. Figure 19 and the accompanying text outline what sub-systems could be implemented into a Pbar GMS system.

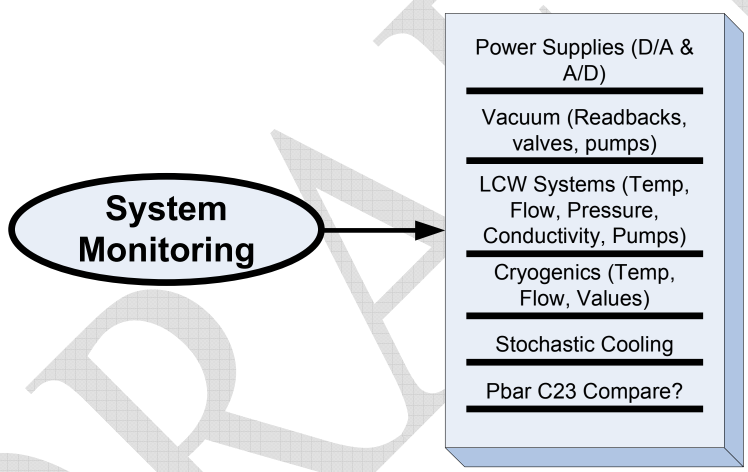

Figure 19: A list of possible systems that the Pbar GMS could be designed to monitor.

1. LCW: Proper cooling of Pbar source devices requires proper functioning of the LCW systems.
    a. Pbar 95 LCW
    b. Chilled Water
    c. Target Station Closed Loop systems
    d. F27 Closed loop system
    e. AP30 and AP50 closed loop systems
2. Vacuum:
    a. Vacuum pump status (monitor frequency of trips?)
    b. Vacuum readback (watch for varience in readback?)
3. Power Supplies
4. Cryogenics
5. Stochastic Cooling
6. RF
7. Target Station

   a. Target Rotation (D:LNRT)

8. Pulsed Devices
   a. Web enabled scopes

Each of the above sub-systems would need to further broken down into individual components. These components would monitored and used to provide an overall indication of heath for each of the individual sub-systems. This document does not yet cover this information.

Systems Monitoring via an ADC Compare Program

One possible alternative to implementing the systems portions of the Pbar GMS, would be to create a Pbar addition to Acnet ADC Compare Program. This program is used by either users or sequencers to compare parameter readings and/or settings to a nominal file. The original ADC compare program was written for the Tevatron, but there are now versions for the Recycler (R100) and the Booster (B22). Each version of the program has a list of devices with nominal settings and readings with a defined tolerance for each operational state for that accelerator. For example, Tevatron has separate C23 save files for all of its operational states including HEP, proton injection front porch, pbar injection porch, before ramp, flattop, squeeze, etc… Each operational state has one nominal file that represents the default operating conditions. The user is allowed to save the current readings and/or settings to file, display the contents of a file, compare the contents of two files or compare the active data with data from a file. When active data is compared to the nominal file, either by looking at the settings or the readings, the output list is sorted by result with the entries that fail the comparison listed at the top. By developing valid C23 compares for the different operating states of an accelerator, one can quickly determine the source of failures or poor beam quality even if the alarm screen does not have the appropriate alarm list configuration.

The Big Picture

Let's now pull everything together from our previous sections. A Pbar GMS system could provide a continuous global view of Pbar source operation. It would watch for trends in operation and provide an advanced warning of global problems. It would have three primary categories: auto configuration, beam monitoring and system monitoring. The auto configuration section would allow the Pbar GMS to adjust to both the operational state of the accelerator and the overall beam conditions. Beam monitoring could include both intensity and quality monitoring. System monitoring would include monitoring information from the various Pbar subsystems. Beam and system data would be collected from existing diagnostics and devices, analyzed, compared to baselines of expected operation, and output to a user interface, Acnet parameters or the alarm screen. A functional diagram of the Pbar GMS is shown in Figure 20.

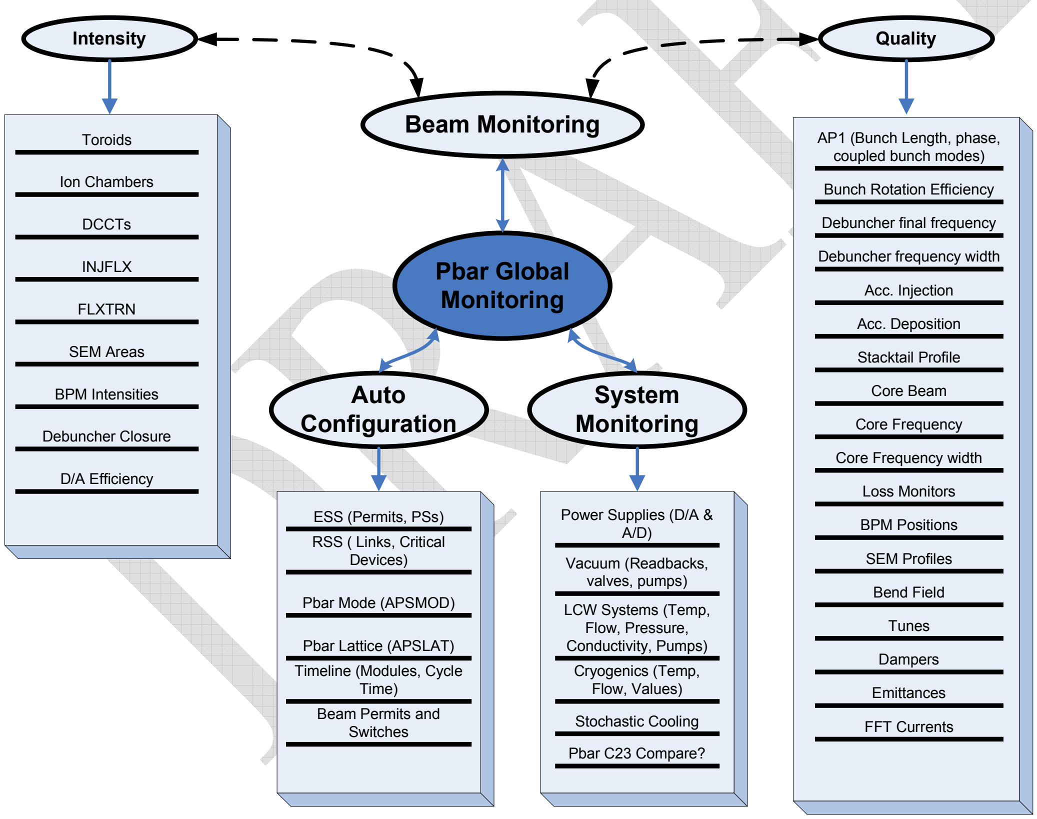

Figure 20: Attaching devices to each of the functional potions of the Pbar GMS.

Long-term Implementation Plan and Recommendations

Clearly to implement all of the features explored in this document into a Pbar GMS would be a massive undertaking. Such a system would require a hardware front end to manage the collection of data, software developed to analyze and collect the data from multiple sources, additional hardware in the form of dedicated spectrum analyzer channels with switch tree access, new Acnet parameters to provide alarms and an output of results, and software developed for a Java user interface. Let's break down the Pbar GMS's implementation into a number of phases.

1. Phase 1: Determine which of the Pbar GMS categories to develop. Based on what we have covered in this document, it may be best to implement the beam intensity and quality monitoring first, followed by auto configuration, and then system monitoring. Some of the system monitoring functionality could be replaced by a Pbar version of C23.
2. Phase 2: For each Pbar GMS category, determine which systems can be implemented into the system. The preceding sections of this document make a first attempt to address this issue. This needs to be a point of active discussion and can change as the system evolves.
3. Phase 3: Determine baselines: Use and develop existing tools such as the Datalogger, Pbar Performance plots, and Java Analysis Studio to determine standardized baselines for both system conditions and beamline efficiencies. After a well-defined set of baselines have been established, start designing the Pbar GMS.
4. Phase 4: Investigate the usefulness of a Pbar version of C23.
5. Phase 5: Design the Pbar GMS: Put together a plan the includes any dedicated spectrum analyzers, front ends and other hardware necessary to build the Pbar GMS.
6. Phase 6: Develop any OACs and software needed to run the Pbar GMS.
7. Phase 7: Develop a user interface for the Pbar GMS.
8. Phase 8: Implement the new hardware designed in phase 5.
9. Phase 9: Deploy Beam Intensity Benchmarking
10. Phase 10: Deploy Beam Operational State Logic
11. Phase 11: Deploy Beam Quality Benchmarking
12. Phase 12: Deploy Systems Benchmarking

Overall, implementing a Pbar GMS would provide us with useful data that would help us automatically monitor the heath of important beam and system components of the accelerator. This document has only started to address Phase 1 and Phase 2 listed above. The next step is to solidify Phase 1 and Phase 2 and start documenting Phase 3.